



Calhoun: The NPS Institutional Archive

Reports and Technical Reports

All Technical Reports Collection

1996-06-11

Improved Efficiency and Power Density for Thermoacoustic Coolers

Hofler, Thomas J.

Monterey, California. Naval Postgraduate School

<http://hdl.handle.net/10945/45992>



Calhoun is a project of the Dudley Knox Library at NPS, furthering the precepts and goals of open government and government transparency. All information contained herein has been approved for release by the NPS Public Affairs Officer.

**Dudley Knox Library / Naval Postgraduate School
411 Dyer Road / 1 University Circle
Monterey, California USA 93943**

<http://www.nps.edu/library>

NAVAL POSTGRADUATE SCHOOL

Monterey, California



Improved Efficiency and Power Density for Thermoacoustic Coolers

by

Thomas J. Hofler

June 1996

Approved for public release; distribution is unlimited.

DTIC QUALITY INSPECTED

Prepared for: Office of Naval Research
ONR 331
Arlington, VA

19960812 095

NAVAL POSTGRADUATE SCHOOL
Monterey, California

Rear Admiral M. J. Evans
Superintendent

R. Elster
Provost

This report was prepared for and funded by the Office of Naval Research, ONR 331,
800 North Quincy Street, Arlington, VA 22217-5660.

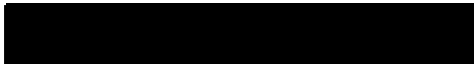
This report was prepared by:



THOMAS J. HOFLER
Associate Research Professor of Physics

Reviewed by:

Released by:



ANTHONY A. ATCHLEY
Chairman, Department of Physics



DAVID W. NETZER
Associate Provost and Dean
of Research

REPORT DOCUMENTATION PAGE*Form Approved*
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information suggestions for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave Blank)		2. REPORT DATE 11 Jun 96	3. REPORT TYPE AND DATES COVERED Technical Report - 01 Jun 95 - 31 May 96	
4. TITLE AND SUBTITLE Improved Efficiency and Power Density for Thermoacoustic Coolers			5. FUNDING NUMBERS PE61153N N0001496WR20003 N0001496AF00002	
6. AUTHOR(S) Thomas J. Hofler				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) PHYSICS DEPARTMENT NAVAL POSTGRADUATE SCHOOL MONTEREY CA 93943-5117			8. PERFORMING ORGANIZATION REPORT NUMBER NPS-PH-96-004	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) OFFICE OF NAVAL RESEARCH ONR331 800 NORTH QUINCY STREET ARLINGTON VA 22217-5660			10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES				
12A. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited			12b. DISTRIBUTION CODE	
13. ABSTRACT (<i>maximum 200 words</i>) Work continues on building a thermoacoustic heat driven cooler having no moving parts, with cooling power in the 0.5 to 1.0 kW range. Previous work dealt with numerical modeling of a new engine topology used in the above engine and various work on improved heat exchangers. Recently, more modeling suggests that cooling powers in the range of 35 kW (10 ton) may be possible with an engine having a longest dimension of 4 ft. and that efficiency improves significantly with size. Also, we have solved some fabrication problems with our high temperature nickel heat exchangers. The major work this year has been on the high temperature thermoacoustic stack structure. A common Stirling engine regenerator structure consisting of stacked disks cut from stainless steel wire mesh was tested in an apparatus previously used for high amplitude heat exchanger measurements. Stacks are very easy to construct in this fashion and longitudinal thermal conduction is greatly reduced. Results show that amplitude performance is very good and within 10% of the usual spiral roll structures. More impressively, the efficiency of the mesh stack is as much as 30% higher than for spiral rolls stacks. We are also conducting measurements on pure carbon random structures that could be used at extremely high temperatures.				
14. SUBJECT TERMS thermoacoustic, refrigeration, heat exchange, heat transport			15. NUMBER OF PAGES	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT	

**Annual Summary Report for
Improved Efficiency and Power Density for Thermoacoustic Coolers**

June 1996

by

**Thomas J. Hofler
Physics Department
Naval Postgraduate School
Code PH/HF
Monterey, CA 93943**

for

**Office of Naval Research
Dr. Logan E. Hargrove ONR 331
Navy Environmentally Safe Ships Program**

ABSTRACT

Work continues on building a thermoacoustic heat driven cooler having no moving parts, with cooling power in the 0.5 to 1.0 kW range. Previous work dealt with numerical modeling of a new engine topology used in the above engine and various work on improved heat exchangers. Recently, more modeling suggests that cooling powers in the range of 35 kW (10 ton) may be possible with an engine having a longest dimension of 4 ft. and that efficiency improves significantly with size. Also, we have solved some fabrication problems with our high temperature nickel heat exchangers.

The major work this year has been on the high temperature thermoacoustic stack structure. A common Stirling engine regenerator structure consisting of stacked disks cut from stainless steel wire mesh was tested in an apparatus previously used for high amplitude heat exchanger measurements. Stacks are very easy to construct in this fashion and longitudinal thermal conduction is greatly reduced. Results show that amplitude performance is very good and within 10% of the usual spiral roll structures. More impressively, the efficiency of the mesh stack is as much as 30% higher than for spiral rolls stacks. We are also conducting measurements on pure carbon random structures that could be used at extremely high temperatures.

Improved Efficiency and Power Density for Thermoacoustic Coolers

TABLE OF CONTENTS

Abstract	i
Table of Contents	ii
I Project description	1
II Approaches taken	1
III Summary of completed work	2
IV Publications/Patents/Presentations/Honors	4
V Distribution List	6

I Project Description

The goal of the proposed basic research is to consider and evaluate new thermoacoustic cooler designs which will lead to substantial improvements in both efficiency and cooling power density. The hope is that this technology will be viable for small temperature span and high cooling power needs such as equipment chilling and A/C. The specific design aspects to be considered are the acoustic resonator, the stack, and the internal heat exchangers. Substantial improvements in both the efficiency and the cooling power density of thermoacoustic refrigerators is necessary in order for the technology to be competitive with existing refrigeration technology.

II Approaches Taken

Reasonably high cooling power densities can be obtained if high acoustic amplitudes and high mean pressures can be used effectively. Acoustic amplitudes having a peak dynamic pressure that is at least 10% of the mean pressure are necessary ($p_o/p_m = 0.1$) and a value of 20% or higher is desirable. Our work focuses on improving the acoustic resonator, the heat exchangers, and stack to work efficiently at these amplitudes. It is also desirable the engine be as compact as possible.

Most of our effort is expended on experimental work, although numerical models are used to evaluate new designs and optimize chosen designs. Some of the experimental work is relatively basic or fundamental in scope, although we are working hard on building a fully working heat driven cooler in the 1 kW range that will integrate all of the basic improvements that we have developed over the previous two years. While the goal of these engines is to use heat sources such as fossil fuels or waste heat to produce refrigeration, our laboratory unit will initially use electric heat for reasons of convenience, simplicity, and to improve the quality of the measurements.

While we have previously focused on acoustic resonators and heat exchangers, this year considerable effort was given to the thermoacoustic stack. Our usual thermoacoustic refrigerator stack consists of a spiral roll of plastic film with thin spacers glued to the surface. These stacks are moderately difficult and time consuming to fabricate. Making comparable stacks for use at high temperatures is a considerably more difficult, since few materials (e.g. adhesives or solders) will tolerate the required temperatures.

Researchers at Los Alamos National Laboratory have successfully fabricated spiral roll stacks using metal foil, for use at high temperatures, but they have two draw-backs. First, fabrication requires a very tricky welding procedure; and second,

a substantial fraction of the engine's heat input is wasted by thermal conduction in metal foil.

We have chosen instead to pursue some basic experimentation on a stack structure that is in common usage in Stirling engine regenerators. This structure consists of stacking disks cut from stainless steel wire mesh into a holder tube. The measurements were done in two phases: Quick and dirty measurements were done in an open liquid nitrogen prime mover (a.k.a. the "Hofler tube") with a large number of different stacks including a spiral roll stack for comparison. Secondly, two good performing stacks from these measurements and another spiral roll stack were measured in a more sophisticated sealed prime mover apparatus. This apparatus had been previously used for heat exchanger measurements.

The results of these stack measurements have been very promising and we plan to use a wire mesh stack for the driver portion of the heat driven cooler engine, and will probably also try a wire mesh stack in the refrigerator portion.

III Summary of Completed Work

Numerical Analysis

A small amount of time was spent modeling a hypothetical heat driven cooler, that is increased in scale relative to the 0.5 kW unit that we are currently building. By selecting moderately aggressive pressure amplitudes and mean pressures and then scaling the dimensions up, we were able to generate results for a 35 kW (10 ton) cooler that is only 4.5 ft. in length. This design is the same as the "dual full wave" topology discussed previously. The calculated total COP is 0.65, and we believe that total COPs approaching unity (heat input equal to cooling power) are possible with a more serious optimization and possibly higher temperatures.

Heat Exchanger Fabrication

We have encountered some difficulty in fabricating some of our heat exchangers. The ambient and cold heat exchangers are easy to make, and have a moderately elaborate support and conduction backbone that is formed by a CNC milling procedure. The backbone pattern is cut into a heavy layer of electroplated copper.

The problem is with the high temperature exchanger which is made entirely of nickel. The electroplated nickel is very hard and tends to destroy cutting tools, and it is also prone to brittleness and breakage.

The simple and highly effective solution was to cut the pattern via a process known as "sink EDM" (electro-discharge machining). The disadvantages are cost and time wasted in procurement.

Engine Construction

Most of the parts are now available for the heat driven cooler. There have been some large procurement delays, particularly with some final heat exchanger pieces. There is a moderate amount of assembly to be done. We hope to have prime mover data and possibly refrigeration data by the end of the fiscal year.

The Mesh Stack

We have performed basic performance measurements on stacks made of stacked wire mesh disks. Initial measurements were made on dozens of different mesh sizes in an open prime mover, in an anechoic chamber. The measured quantities were external temperatures and far field sound pressure. The amplitudes achieved with the best mesh stacks were almost as high as with a spiral roll. The best mesh stacks were made with the most open mesh material we could obtain, which was "bolting cloth" with 10 wires per inch or "bolting-10". The bolting cloth material has extra-fine wires. Surprisingly, the hole size at 10/inch is roughly 3 times larger than the plate separation distance in the spiral roll stack.

Three stacks were then measured in a sealed temperature-controlled prime mover apparatus previously used in heat exchanger measurements. The apparatus allowed mean pressure and stack position to be varied and the heat input power to be measured. Also, internal pressure (dynamic and mean) were measured, as were internal temperatures.

The amplitude performance seen in the open prime mover was again confirmed, with the spiral roll being the best, followed by the "bolting-10" mesh, followed by "bolting-16." The amplitude difference was approximately 10% between the spiral roll and bolting-10. The highest amplitude for bolting-10 was $p_o/p_m = 29\%$.

The more interesting data was the "efficiency" data. Let me emphasize that the only acoustic load on the stack was the resonator itself. Furthermore, the acoustic power dissipated by this load was not measured but only inferred by assuming a quadratic dependence on amplitude. Comparing the results for the three different stacks suggest that the efficiency of bolting-10 and bolting-16 stacks were identical and were generally higher than for the spiral roll. In some cases the mesh stack efficiencies were 30% higher than for the spiral roll stack.

We are currently taking data in the same apparatus with stacks fabricated with a random carbon material. The amplitude data looks good and the "efficiency" data is currently being analyzed.

**OFFICE OF NAVAL RESEARCH
PUBLICATION/PATENTS/PRESENTATIONS/HONORS REPORT
for
01 June 95 through 31 May 96**

Contract/Grant Number: N00014-96-WR-20003 and N00014-96-AF-00002

Contract/Grant Title: Improved Efficiency and Power Density for Thermoacoustic Coolers

Principal Investigator: Thomas J. Hofler

Mailing Address: Physics Department
Code PH/HF
Naval Postgraduate School
833 Dyer Road
Monterey, CA 93943-5117

Phone Number: 408-656-2420

Facsimile Number: 408-656-2834

E-mail Address: hofler@physics.nps.navy.mil

a. Number of papers submitted to refereed journals but not yet published:	<u>0</u>
b. Number of papers published in refereed journals (ATTACH LIST):	<u>0</u>
c. Number of books or chapters submitted but not yet published:	<u>0</u>
d. Number of books or chapters published (ATTACH LIST):	<u>0</u>
e. Number of printed technical reports & non-refereed papers (ATTACH LIST):	<u>0</u>
f. Number of patents filed:	<u>0</u>
g. Number of patents granted:	<u>0</u>
h. Number of invited presentations at workshops or professional society meetings:	<u>1</u>
i. Number of contributed presentations at workshops or professional society meetings:	<u>2</u>
j. Honors/awards/prizes for contract/grant employees, such as scientific society and faculty awards/offices (ATTACH LIST):	<u>1</u>
k. Number of graduate students supported at least 25% this year on this contract/grant:	<u>0</u>
l.. Number of post docs supported at least 25% this year on this contract/grant:	<u>0</u>

How many of each are females or minorities? These six numbers are for ONR's EEO/Minority Reports. Minorities include Blacks, Aleuts, Amindians, etc., and those of Hispanic or Asian extraction/nationality. The Asians are singled out to facilitate meeting reporting semantics re "underrepresented".

Graduate student FEMALE: 0
Graduate student MINORITY: 0

Post doc FEMALE: 0
Post doc MINORITY: 0

Graduate student ASIAN E/N: 0

Post doc ASIAN E/N: 0

P³H Report Continued
01 June 95 through 31 May 96

Honors/Awards,/Prizes, etc.

Promoted to Associate Research Professor of Physics, Naval Postgraduate School

Distribution List

Under Grant N0001496WR20003 and N0001496AF00002

Annual Summary Report

	# of Copies
1. Defense Technical Information Center Building 5, Cameron Station Alexandria, VA 22314	2
2. Dr. Logan Hargrove ONR 331 Office of Naval Research 800 North Quincy Street Arlington, VA 22217-5660	2
3. Naval Research Laboratory Technical Library, Code 5226 4555 Overlook Avenue, SW Washington, DC 20375-5320	1
4. Naval Postgraduate School Technical Library, Code 52 Monterey, CA 93943	2
5. Professor W. Patrick Arnott Atmospheric Sciences Center Desert Research Institute P.O. Box 60220 Reno, NV 89506	1
6. Professor Henry E. Bass Department of Physics and Astronomy University of Mississippi University, MS 38677	1
7. Professor Richard Raspet Department of Physics and Astronomy University of Mississippi University, MS 38677	1
8. Dr. Gregory W. Swift Los Alamos National Laboratory MS K764 Los Alamos, NM 87545	1

9. Dr. David L. Gardner 1
Los Alamos National Laboratory
MS K764
Los Alamos, NM 87545
10. Professor Cila Herman 1
Department of Mechanical Engineering
G.W.C. Whiting School of Engineering
3400 N. Charles Street
Baltimore, MD 21218-2686